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The use of co-operative work and rubrics to develop competences

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ABSTRACT

Some of the most important engineering skills required nowadays, such as the ability to co-operate to find appropriate information, to solve problems through critical and creative thinking, to make decisions and to communicate effectively, are dealt with in this study carried out with chemical engineering students. The study investigates how certain competences needed by students may be developed through co-operative learning. Learners were given clear evaluation rubrics to know what was expected of them. Data were obtained from a survey form, assessment results and meetings with individual groups. The main results indicate that the teacher's involvement in creating a challenging, integrated teaching unit and students' effort in co-operating to create their final written and oral reports led to considerable improvement in understanding unit operations as well as to very high student motivation. The data support the hypothesis that well-defined comprehensive protocols, rubrics and co-operative work direct students towards successful learning.

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Keywords: Unit operations; Rubric; Co-operative learning; Competences; Chemical engineering

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The use of co-operative work as a teaching strategy can help to improve students' sense of responsibility for their own learning by fostering group cohesion and positive interdependence among peers (Humphreys et al., 1982; McKeachie et al., 1986; Scott-Ladd and Chan, 2008). Research studies report collaborative learning as one of the most effective forms of

learning (Tjosvold et al., 1977; Johnson and Johnson, 1990; Mills and Woodall, 2004; Drake et al., 2006) as learners learn content and develop interactional competences at the same time. Its basic philosophical keystone is that through co-operation more can be achieved than through individual work and competition (Humphreys et al., 1982).

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First-year students entering a new academic setting need to learn to connect with other students and teachers (Garvin et al., 1995). In Mills and Woodall's study (2004) on group project work with undergraduate students, the most highly rated response to group work was that of "meeting their colleagues." Co-operative work for first-year students may be a way of starting to get to know their peers and also to become actively engaged in deep learning (Gibbs, 1992; Entwistle, 1993; Machemer and Crawford, 2007). As they have to become 'experts on a given topic' and then to present it to their classmates, many decisions have to be taken. It is precisely the discussions that are produced that have been reported as a central element for learning in collaborative situations. However, this does not imply that it can be done without assistance and guidance. The well-defined instructions, well-planned tasks, sufficient amount of appropriate references, individual and/or group tutorship and explicit assessment criteria, all of which being part of the teacher's guidance, are important ingredients to promote a successful learning atmosphere.

Some authors claim that explicit assessment criteria in higher education may have a deleterious effect on students' learning, if this leads students to focus mainly on strategies on how to pass their examination rather than on deep learning (Norton, 2004). New teaching techniques require appropriate types of assessment such as portfolios, oral presentations or interviews, among other possible options. All of these types of assessment may include rubrics that will make assessment criteria clear and that facilitate more successful learning. Dunbar et al. (2006) state that "rubrics can be an influential tool in faculty development efforts in terms of developing and maintaining consistency among teachers."

This study investigates how certain competences needed by chemical engineering students may be developed through the use of co-operative work as a teaching strategy and rubrics as assessment criteria shared by the teacher and the students.

1. Materials and methods

1.1. Topic

The topic chosen, 'unit operations', is not dealt with in studies in secondary schools, which implies that when they began their chemical engineering classes, it was the first time that students faced the new terminology and concepts. The topic is central to the chemical engineering degree as unit operations are the basic step in industrial chemical processes. Unit operations refer to those processing steps that occur with certain equipment that are used sequentially to convert raw materials into marketable products. Most unit operations are based mechanistically upon the fundamental transport processes of mass transfer, heat transfer and fluid flow (momentum transfer). In this study, one unit operation per transport process was assigned to each group (Fig. 1).

The unit operations approach serves as a useful mechanism to introduce new students to chemical engineering terminology and is a very powerful form of morphological analysis of the chemical process, greatly reducing the number of concepts that must be taught in a particular process. Furthermore, it helps students to understand that the wide range of unit operations existing in the chemical industry may be unified under the understanding of the three transport phenomena (mass transfer, heat transfer and momentum transfer).

| Based on mass transfer | | GROUP A |
|---------------------------------|-----|-------------|
| Distillation | MA1 | MA1 HE1 MO1 |
| Liquid-liquid Extraction | MA2 | |
| Leaching | MA3 | |
| Adsorption | MA4 | |
| Ion exchange | MA5 | |
| Absorption/desorption | MA6 | |
| Membrane separation process | MA7 | |
| Based on mass and heat transfer | | GROUP B |
| Crystallization | MH1 | MA2 MH1 MO2 |
| Liofilization | MH2 | |
| Drying | MH3 | |
| Humidification/dehumidification | MH4 | |
| Based on heat transfer | | GROUP C |
| Furnaces/kilns | HE1 | MA3 HE2 MO3 |
| Heat exchange | HE2 | |
| Evaporation | HE3 | |
| Based on moment transfer | | GROUP D |
| Pumping | MO1 | MA4 MH2 MO4 |
| Mixing/agitation | MO2 | |
| Fluidisation | MO3 | |
| Clarification/Sedimentation | MO4 | |
| Centrifugation | MO5 | |
| Filtration | MO6 | |
| Particle size reduction | MO7 | |
| | | GROUP E |
| | | MA5 HE3 MO5 |
| | | GROUP F |
| | | MA6 MH3 MO6 |
| | | GROUP G |
| | | MA7 MH4 MO7 |

Fig. 1 – Subtopics (modules) of the topic unit operations and groups to which they were assigned.

1.2. Students

First-year students ($n=24$) of the chemical engineering degree were enrolled in the course 'Introduction to chemical engineering' (see Table 1). Seven of them were male students and 14 were female students; all of them were aged between 18 and 21 years. It should be considered that values higher than 24 in Table 1 are a consequence of the inclusion of a number of students who had to take the subject again as they had failed in it.

No pre-test was necessary, because all undergraduates enrolled in the university had passed a university entrance examination and all the students had a similar academic level in science.

Table 1 – Subjects making up the first course of industrial chemical engineering bachelor and registered students in each one.

| Subjects | Short name | Registered students |
|---|----------------|---------------------|
| Mathematical foundations of engineering | Math Found | 66 |
| Physical foundations of engineering | Phy Found | 73 |
| Graphical expression and computer aided design | Graph Exp | 59 |
| Chemistry foundations | Chem Found | 37 |
| Organic chemistry | Org Chem | 61 |
| Computer science foundations | Comp Sci Found | 101 |
| Unit operations | Unit Op | 36 |
| Business administration and output organization | Buss Adm | 38 |
| Analytical chemistry | Anal Chem | 25 |
| Introduction to chemical engineering | Int Chem Eng | 28 |

Table 2 – Evaluation rubrics for both oral presentation and written report.

| Oral presentations | | | | | |
|------------------------------|--|---|--|--|--|
| Category/score | 4 | 3 | 2 | 1 | 0 |
| Presentation style | The group used appropriate outlines and videos to explain unitary operations. Gestures, eye contact and tone of voice got the audience's attention | In general, gestures, eye contact and tone of voice got the audience's attention | Sometimes, the group used gestures, eye contact and tone of voice to maintain the audience's attention | One group member did not use a proper presentation style to catch audience's attention | More than one group member did not use a proper presentation style to catch audience's attention |
| Content | An abundance of material clearly related to unitary operations; points are clear | Sufficient information that relates to unitary operations; many good points made | There is a great deal of information that is not clearly connected | Some incorrect information included | In general, information is not of good quality |
| Topic understanding | The team clearly understood the unitary operations assigned and presented their content in an energetic and convincing way | The team clearly understood the unitary operations assigned and presented their content in a satisfactory way | The team seemed to understand the main points of their content | Some team members seemed not to understand the assigned operations | The team in general seemed not to understand the assigned operations |
| Participation in discussions | Provided many good ideas for the unit development; inspired others; clearly communicated ideas and questions | Participated in discussions; paid attention to others and asked good questions | Listened mainly; on some occasions, made suggestions | Rarely spoke up or made questions | No participation in discussions |
| Teamwork | Presentation shows that previous group discussion and planning has taken place | Individual tasks are interrelated | There seems to have been some collaboration in the global structure of their presentation | Mostly individual work joined together | No teamwork observable |
| Written report | | | | | |
| Category/score | 4 | 3 | 2 | 1 | 0 |
| Organization | Content presented in well-organized paragraphs. They include subheadings | Organized content developed into paragraphs | Organized content but without well-developed paragraphs | Content poorly organized | Content does not seem organized |
| Quality of content | Content explains all points that are need to be included, fosters reader's learning and adds interesting examples | Sufficient information that relates to unitary operations; many good points made | There is a great deal of information that is not clearly connected | Some incorrect information included | In general, information is not of good quality |
| Diagrams and illustrations | Diagrams and illustrations are organized, precise and provide strong support | Diagrams and illustrations are precise and help to understand the text | Not all diagrams and illustration are of value to facilitate understanding of the report | Diagrams and illustrations are not of sufficient value | No diagrams or illustrations |
| Questions | All questions summarize the main points of the report | The majority of questions summarize the main points | Only some questions are related to main points | No questions of real interest | No questions at all |
| Use of the Moodle platform | All group members have participated in the discussion forum to solve problems | The majority of group members have participated in the discussion forum to solve problems | Some group members have participated in the discussion forum to solve problems | Only one of them has participated in the discussion forum to solve problems | None of them have participated in the discussion forum to solve problems |
| References used | All content and graphics are well-referenced | Nearly all content and graphics are well-referenced | Some content and graphics are well-referenced | Few content and graphics are well-referenced | No content and graphics are well-referenced |

Students were divided into groups of three or four and each group was assigned three different unit operations, according to the protocol described above (Fig. 1). Their oral presentations, guided and supervised beforehand by the teacher, resulted in good peer teaching. Tutorials with each group were of special help as online and face-to-face discussions increased the cognitive quality of student responses, promoting a deeper and more meaningful understanding of course content.

Three learning outcomes were expected:

- (1) Higher learner motivation as a consequence of sharing responsibilities and effort to solve a complex task.
- (2) The development of deeper knowledge of fundamental principles of the most important unit operations used in chemical and process industries (mission; fundamentals of fluid flow, heat transfer and mass transfer involved in each unit operation; operating unit modes; etc.).
- (3) Development of students' ability to find appropriate information, to solve problems through critical and creative thinking, to make decisions as well as to communicate information and decisions effectively.

1.3. Teaching methodology

The teacher presented a comprehensive protocol to the whole group in class, including the main aims of the task, its description, the timing and sequencing of each step to be followed, assessment criteria and basic references. To assist students through virtual tutorship and to facilitate teamwork, the teacher created an online course on the Moodle platform where students could interact with the teacher and also among themselves. The teacher's role was that of regulator of conflicts, observer, guide and evaluator.

1.4. Discussion forum

Students identified their learning needs, searched for information and generated ideas while the teacher constantly assisted them through regular interview sessions and asynchronous online exchanges. Final reports were handed to the teacher and oral presentations were given to the whole class where the teacher and the group who made the presentation resolved any final doubts. Each final written report was also made available online on the Moodle platform. Students were helped to create good PowerPoint presentations to support their oral presentations. Finally, students were allowed 30 min to explain their three unit operations, while the rest of the class had to pose questions of interest at the end of each presentation to direct the debate. The evaluation rubrics (Table 2) created by the teacher helped students to understand what exactly was required to obtain a specific mark.

1.5. Evaluation procedures

Assessment was considered of special importance to guide students' achievement. Several evaluation procedures were used to assess content and competences:

- follow-up of students' participation in the group task;
- evaluation of final report according to rubrics;
- evaluation of oral presentation according to rubrics and responses given to questions; and
- survey form for students to evaluate teamwork, competences development, learning outcomes and tutorials.

2. Results and analyses

The following tables and charts show the results of this study.

(1) *Follow-up of students' participation in group task*: Students were free to organise their working groups and meetings. The teacher helped students to state the objectives of their group task as they were going to be evaluated by group results, not individually. In the beginning, students' participation in the group task was not strictly monitored by the teacher. However, the progress of each group of students was followed in three tutorials, where discussions between teacher and students regarding the subject took place. Thus, the different groups found the tutorials helpful as they obtained knowledge regarding unit operations and were guided towards significant improvement in their reports.

Blended learning was also considered a relevant factor. The Moodle platform was used to let students interact with the teacher, and also among themselves through chat lines and e-mails. Although the teacher had explained the advantage of using the chat line for team working, it is worth pointing out that the number of entrances for chat lines was low. This could be a consequence of first-year students not being familiar with this e-learning software platform and, therefore, they preferred meeting face-to-face. In this sense, it could be of special benefit to train students better in the use of these virtual interactive tools, as they could facilitate interaction among group members.

To be able to appreciate the effect on students' learning of any teaching activity, feedback is needed and may be considered one of the most important aspects to evaluate teachers' methodology. For this reason, a survey assessment was designed and students were asked to write their opinions about the co-operative approach in the learning of unit operations. Data obtained from the survey are discussed below.

(2) *Data obtained from survey form*: In a science or technical degree, one competence that is important for students to develop is learning to investigate and to present the results of their work. These abilities require using different capacities for obtaining information in an effective way to organise tasks, to assess information, to compile reports and to present them publicly. An assessment survey was designed to evaluate the impact of the co-operative learning methodology on

Table 3 – Students' assessment on skills related to information management.

| How did the activity improve your information searching, analysis and synthesis skills? | | | | | |
|---|----------------|--------------|----------|-----------------|---------------|
| | Not at all (%) | A little (%) | Some (%) | Quite a lot (%) | Very much (%) |
| Information searching | 0.0 | 5.3 | 21.1 | 31.6 | 42.1 |
| Analysis | 0.0 | 0.0 | 40.0 | 25.0 | 35.0 |
| Synthesis | 0.0 | 0.0 | 30.0 | 35.0 | 35.0 |

Table 4 – Teamwork assessment.

| How do you value teamwork to develop your learning on unit operations? | | | | |
|---|-----------------------|--------------|-----------|--------------------|
| | Strongly disagree (%) | Disagree (%) | Agree (%) | Strongly agree (%) |
| I felt motivated | 0.0 | 5.3 | 47.4 | 47.4 |
| I have invested too much time | 0.0 | 33.3 | 50.0 | 16.7 |
| There has been interaction with the rest of the group | 10.0 | 45.0 | 20.0 | 25.0 |
| Working alone, I would have done more and better | 50.0 | 35.0 | 15.0 | 0.0 |
| I was able to solve conflicts with other group members | 11.1 | 22.2 | 55.6 | 11.1 |
| I have learnt from my classmates | 0.0 | 5.0 | 55.0 | 40.0 |
| I think that content given by the teacher is more valid than that given by peers. | 0.0 | 50.0 | 44.4 | 5.6 |
| I prefer this way of learning to the traditional way | 5.3 | 63.2 | 15.8 | 15.8 |
| I had repeat teamwork with the same group members | 0.0 | 20.0 | 40.0 | 40.0 |

Table 5 – Students' assessment on the degree of skills developed.

| Does this way of working strength any skills which improve your learning? | | | | |
|---|-----------------------|--------------|-----------|--------------------|
| | Strongly disagree (%) | Disagree (%) | Agree (%) | Strongly agree (%) |
| I have developed the ability to communicate about unit operations and to use correct terminology about the subject. | 0.0 | 26.3 | 68.4 | 5.3 |
| I have increased my capacity to extract the essential aspects of a topic | 0.0 | 10.0 | 60.0 | 30.0 |
| I have developed my capacity to think, to review, to reflect and to mature an idea before taking a decision. | 0.0 | 20.0 | 55.0 | 25.0 |
| Taking into account the opinion of the rest of the group has improved the result of the work | 5.0 | 5.0 | 50.0 | 40.0 |
| I have contributed to the final report by making suggestion and ideas carrying out the activity and I have committed myself to develop it | 0.0 | 10.0 | 50.0 | 40.0 |
| I have helped my classmates with their work | 5.0 | 25.0 | 45.0 | 25.0 |
| I have learnt to share materials and tasks with my classmates | 0.0 | 5.0 | 50.0 | 45.0 |

development of skills and information management issues (see Tables 3 and 4).

Table 3 shows the results of the assessment survey related to the opinions of all students regarding their information management skills. As can be seen, more than 60% consider that this activity helped them to reason, analyse and summarise the information found from the recommended references and not only to copy it. Moreover, one-third of the students affirm that they have improved their skills for searching for information related to chemical engineering in the library and the Internet.

In general, the classroom atmosphere that was created promoted both interpersonal relationships and co-operative learning. On the one hand, the teacher helped students to feel part of the group, favouring teamwork and encouraging students to solve conflicts among themselves. On the other hand, although more than 66.7% of students considered that they invested a great deal of time in finishing this activity, more than 94.8% have pointed out that this learning methodology is motivating for them. Teacher's guidance and selection of appropriate materials helped the different groups to become successful in this task and to feel more self-confident when they had to show their results through oral presentation.

First-year students come from a variety of secondary schools where they are used to working individually. They had never worked together with any of their new classmates. However, all students have appreciated this way of working to solve complex problems, and none of them has considered that by working alone they would have done more and better. Further, interaction among groups, transferring the information found and helping each other, has been positively evaluated by at least 45% of students. Another outstanding fact is that although half of the class seems to place more trust

in information given by the teacher, 95.5% of the students consider that they have learnt from the work presented by their classmates. This fact shows that this methodology involving students' autonomy can be a useful alternative to traditional learning. Special attention was paid to issues related to group work that can help the teaching/learning process (Table 4).

As regards acquisition and development of skills, 70% of the students pointed out that, in all cases, this learning methodology helps them to develop useful professional and social skills (Table 5). Likewise, it is worth mentioning that the majority of students have felt quite committed to developing the final report from the beginning to the end, to learning to work in teams and to sharing materials and tasks with their classmates. Seventy percent pointed out that they have helped some of their classmates finish their tasks, which contributed to the successful completion of the teamwork.

(3) *Evaluation of final reports and oral presentations:* Table 6 shows the grades obtained in students' written reports and oral presentations. Rubrics were very helpful in guiding students in their learning process. Using rubrics would seem to be

Table 6 – Group' marks of final reports and oral presentation.

| | Written report (max. 4) | Oral presentation (max. 4) |
|---------|-------------------------|----------------------------|
| Group A | 3.5 | 4 |
| Group B | 3.5 | 2.5 |
| Group C | 4 | 3 |
| Group D | 3.5 | 3.5 |
| Group E | 3 | 3 |
| Group F | 4 | 3.5 |
| Group G | 4 | 3 |

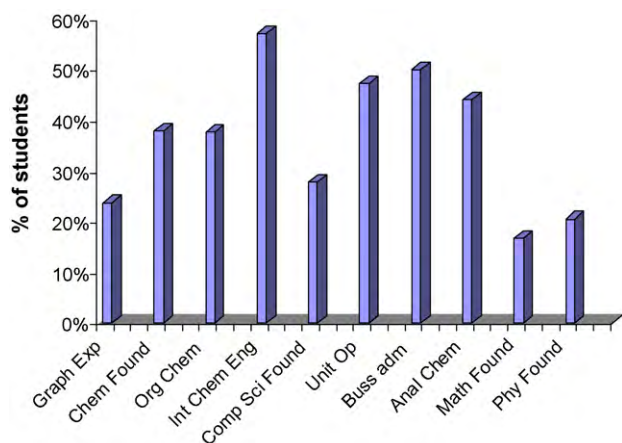


Fig. 2 – Percentages of students that passed the subjects of the first course of the industrial chemical engineering degree.

a good teaching and evaluation strategy to enhance students' success.

(4) *Impact of co-operative work and rubrics on students' marks in comparison with the rest of the subjects in the first-year course:* Fig. 2 shows the percentage of students who have passed the different subjects in the first course of industrial chemical engineering degree at the University of Huelva (see Table 1) during the academic year 2007/2008. As can be observed, 'Introduction to chemical engineering', designated in Fig. 2 as 'Int Chem Eng', shows the highest percentage of students passing the course. It seems to be that a teaching strategy based on co-operative work leads to better results.

Given the difficulty of the first academic year for university students, mainly due only to the complexity of subjects not studied before and also due to inappropriate teaching methods for their academic level (Escandel et al., 2001; Scott and Graal, 2007), students often are resigned to the impossibility of passing the first course successfully and sometimes abandon the degree. Further, as Elton (1988) mentioned, students often fail needlessly because they do not make all possible efforts. If they are reassured that they have the ability to pass the course, they are likely to deliberately adopt a strategic approach, aiming to achieve a pass but not much more. In this sense, the use of co-operative work and rubrics as teaching strategies contributed to increase students' motivation.

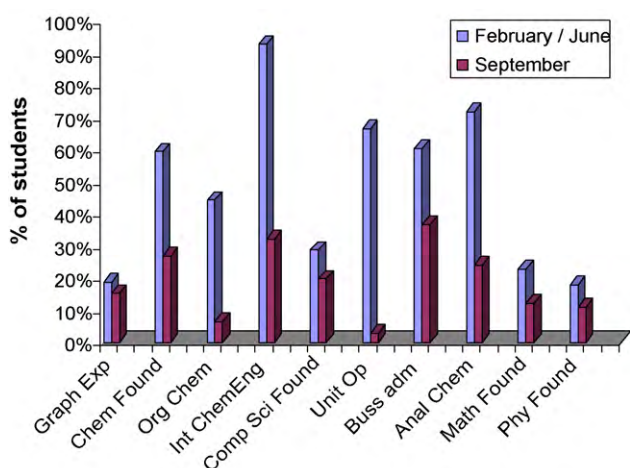


Fig. 3 – Percentages of students who took exams both in February/June and September.

They not only worked to pass the examination, but also did it collaboratively to learn about unit operations. No student dropout was registered. Thus, the development of greater student responsibility for their own learning by fostering group cohesion and positive interdependence among peers put students in a better position for deep learning. In fact, Fig. 3 shows that the highest percentage of students who took the official examinations (February or June and September) corresponded to 'Introduction of chemical engineering', where the methodology described was used. This fact is also relevant as these students have not dealt with chemical engineering terminology in their secondary studies, whereas with math (Math Found), physics (Phy Found), chemistry (Chem Found) and graph expression (Graph Exp), students have had previous contact with the terminology. Co-operative work seems to be a learning methodology that makes students become more deeply involved in the subject, increasing their possibilities for passing the examinations, as it has been indicated in Figs. 2 and 3.

3. Conclusions

Planning plays a central role in any good teaching practice. Teacher's knowledge of content and knowledge of methodological procedures that best suit learning objectives are two keystones that lead to students' success. However, evaluation tools adapted to methodological procedures are relevant as well.

Teacher guidance based on a well-defined protocol to help students to work co-operatively and on clear evaluation rubrics so that learners would know exactly what was expected of them constitutes a possible alternative to lecturing. The teacher's involvement in creating a challenging, integrated teaching unit and students' effort in co-operating to create their final written and oral reports lead to significant improvement in learners' understanding of unit operations as well as to very high student motivation.

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